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COMPUTER CONTROL OF A MACHINE FOR EXPLORING MARS

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Abstract: Landing a 5000 pound package on Mars that would spend a year looking for life and making other measurements has been proposed. We believe that this machine should be a stored program computer with sense and motor organs, and that the machine should be mobile. We discuss the following points:

1. Advantages of a computer controlled system.

2. What the computer should be like.

3. What we can feasibly program the machine to do given the present state of work on artificial intelligence.

4. A plan for carrying out research in computer controlled experiments that will make the Mars machine as effective as possible.

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In 1969 or 1971 we can land 5000 pounds on Mars. The machine we land can have 300 watts of power, can communicate from 10,000 to 100,000 bits per second back to earth according to the distance between earth and Mars. The machine should be able to operate for a year. These facts were taken from a General Electric study called Beagle after the ship that took Darwin around the world. The Beagle study does not discuss the possibility of making the machine mobile, but we believe this can and should be done even if the power limitation makes it go very slowly. We shall follow G. E.'s lead and call the machine the Beagle.

The Beagle should obtain as much information as it can about Mars and radio it back to earth. Naturally, the most interesting question is whether there is life on Mars and if so what it is like. Therefore, we can set forth three goals.

1. To carry out as thorough a search for life as possible, i.e., to maximize the probability that if life exists on Mars, Beagle will find it.

2. If life exists to find out as much as possible about its chemistry, physiology, and ecology. Chemistry will be emphasized because the same means that detect life may also be used to study its chemistry.

3. To find out anything about the environment of Mars that will help future exploration, especially manned exploration.

Why Computer Control of the Beagle:

Up to now space probes have consisted of a collection of separate experiments sharing propulsion power supply and telemetering. We believe that Beagle will be much more effective if it is a computer with sense organs and motor organs and the experiments are represented by computer programs each of which uses the sense and motor organs in a co-ordinated way. Beagle differs from previous space experiments in a number of ways that are relevant to this preference.

1. A large number of sense and motor organs can be included in a 5000 pound machine.

2. Many of the experiments can use common facilities of manipulation, picture recognition, etc.

3. If Beagle works for a year the results of the early experiments will make changes desirable in later ones.

These needs of the Beagle mission can best be met by a computer controlled system. A brief statement of the reasons follows:

1. The control circuitry of each sensory or motor device can be reduced to a minimum if the whole system is computer controlled.

2. The strategy of each experiment can be chosen freely by writing suitable programs even after the hardware decisions have been made.

3. New programs can be written and transmitted from the earth even after Beagle is on Mars.

<u>The Computer and Its Programming</u>:

In this section we shall discuss the features that the Beagle computer should have.

1. It should be light, compact, fast, have a large memory, and be reliable. We shall not discuss how these features can be achieved in this paper, but many companies are working on the problems involved, and we are quite sure a suitable computer will be available.* Suitable parameters might be

- 1.1 weight - 100 lbs.
- 1.2 volume - 2 cu. feet.
- 1.3 memory cycle 1 μ sec - add instruction 2 μ sec - floating multiply - 10 μ sec.
- 1.4 power consumption - 40 watts.
- 1.5 memory 130,144 - 48 bit words.

If these goals are too hard to meet, some compromises are possible, but even higher performance might be helpful.

2. If possible, the system should not use mechanical secondary storage, e.g. tapes or drums. They make reliability difficult.

3. The system must be able to recover from programming errors in programs that carry out particular experiments. Otherwise, it will be impossible to allow the wide variety of programs necessary to make use of the flexibility of a computer based system. In particular, it would be difficult to allow the revision of programs from the earth on the basis of preliminary experimental results if an error in such a revision could cripple the whole machine.

* I don't want to suggest that reliability will come automatically, only that I don't have anything important to say about it.

The ability to recover from programming errors can be achieved by the same devices as one beginning to be used to make time-sharing monitor systems proof against user errors. The necessary features are available on the Digital Equipment PDP-1 and PDP-6 computers, on the IBM 360 computer and partially on the IBM 7090 and 7030 computers. In fact, the Beagle computer should be operated with a time-sharing system, although the Beagle monitor must differ substantially from time-sharing systmes oriented towards computation centers. The important features of time-sharing systems are the following:

1. The system has a user mode and an executive mode. When in user mode the use of input-output instructions is inhibited and attempts to change memory outside an area reserved to a particular program leads to interrupts to the executive program.

2. A clock leads to an interrupt of the executive every so often anyway. (Say, every millisecond). The executive then decides what program should be executed next for a quantum of time.

3. Input or output devices generate interrupts to an appropriate part of the executive program whenever input becomes available or an output device is ready for more.

The core of the executive program must be absolutely debugged, but protection can be provided against errors in large parts of the executive (e.g., the programs that handle input-output devices) by allowing earth generated interrupts to a part of the executive that can be instructed to make changes in the rest of it.

We envisage the program to be divided into four parts.

1. The time-sharing executive - divides the time among the application programs.

2. Housekeeping programs. Handle communication with earth, temperature control management of the energy and supply, control of the motion of the machine.

3. Programs for operating devices. Used as subroutines by the programs that run experiments. Normally contain checks to make sure the devices are not damaged.

4. Programs for running experiments. These are written under the supervision of the experts in the field in which the experiment is performed. The time-sharing system permits them to be written independently of each other.

Mobility:

The effectiveness of the Beagle will be greatly enhanced by mobility. There are two difficulties. First, an average power of 250 watts will not move a 5000 lb. vehicle very fast, and not all the power is available for that purpose. Second, the motion cannot be directly controlled from the earth because the response delay varies from a little over six minutes to almost 25 minutes.

The first difficulty can be overcome by accepting very slow progress (e.g., 10 cm/sec to 100 cm/sec depending on terrain) at times when the experiments and information transmission require very little energy. The second problem must be solved by developing computer programs capable of steering the vehicle past obstacles over different terrains.

Mobility is important for the following reasons:

1. Beagle might land in an unsuitable place, e.g. on bare rock or in a ditch.

2. Beagle should be able to look for high points from which to transmit pictures of the landscape.

3. Features that looked interesting in pictures could be examined at close range.

4. The search for life will be more effective if Beagle can go look for it.

<u>Artificial Intelligence</u>:

Research labelled <u>artificial intelligence</u> is aimed at making computers perform tasks that require intelligence when performed by humans. The exploration of Mars involves many such tasks. If the artificial intelligence problem were completely solved we could expect to send a computer to Mars with no control from earth and have it send back all the information that could be acquired by a large manned expedition. In fact, it is very unlikely that results comparable to manned exploration will be achievable by computer controlled machines within the next twenty years. However, many of the subsidiary tasks are within or near the present state of the programming art especially if the machine can be instructed from the earth if it gets stuck.

Some of the tasks are:

1. Controlling the telemetering so as to submit information at the maximum rate compatible with the orientation of Mars and the distance from Mars to earth. Information of lower priority can be saved for later transmission at times when high priority messages have to be sent.

2. Compression of information. Sending only deviations of an instrument reading from its expected value based on previous readings. Picture compression is more difficult but some results have been achieved.

3. Picture recognition. In various forms, picture recognition is required for a number of Beagle's tasks. Some of these are:

3.1 Recognizing types of terrain and obstacles so that Beagle can obey orders to move.

3.2 Recognizing the lands of materials it has been ordered to collect for analysis.

3.3 Co-ordinating the devices that pick up samples and subject them to analysis.

4. Motor co-ordination, co-ordination of the "hands" and wheels and "legs".

5. Other experimental strategies.

The assumption that the computer can be programmed to achieve the above goals relies heavily on the ability to reprogram it from the earth when unexpected conditions are encountered. We do not expect the state of work in artificial intelligence by 1970 to make the following feasible.

1. To put in the program our concepts of what is interesting.

2. To define life well enough so that the machine would recognize any form of it.

3. To make the program adaptable to any terrain without further instruction. e.g., swamps or mountains.

Projects:

The problem of making good use of a 5000 pound payload is very difficult. A number of investigations should be started right away if the Saturn V rocket is to be used when it becomes available. Some of these projects are:

1. Design of a suitable computer. We assume that the work on small, light, reliable and fast computers with low power consumptions is proceeding. We are less confident that the computer companies will come up with system designs suitable for the sophisticated programming that would be required. The Stanford Computer Science Division would be interested in helping with the order code, input-out structure, and system program design for such a computer.

2. Artificial Intelligence. Anything that can be learned about how to make machines behave intelligently will eventually be of use in unmanned planetary exploration. The most critical problem for Beagle, however, is the visual pattern recognition necessary for selecting and picking up samples and for steering a vehicle past obstacles to a goal. The more we can achieve in general purpose manipulation the less it is necessary to rely on Rube Goldberg contraptions for raising antennas, picking up samples, righting the machine after landing, etc.

3. <u>A sample collector</u>. The mechanical engineering of a device for picking up and breaking and crushing samples should be undertaken soon.

4. <u>A vehicle</u>. The low power that is likely to be available calls for a special vehicle design. For example, a crab that uses the same organs for mobility and for picking up things may be appropriate.

We believe that work aimed at a prototype Beagle that can be tried out on earth should be started as soon as possible. We are eager to help with this.